JD13

Extragalactic Binaries

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Editors: I. Ribas (Chief-Editor) and A. Giménez

https://doi.org/10.1017/S1539299600016130 Published online by Cambridge University Press

Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

Joint Discussion 13: On Extragalactic Binaries

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Abstract. In this paper we discuss the impact of extragalactic binaries on astrophysics and briefly summarize the oral papers presented in Joint Discussion 13.

1. Introduction: Extragalactic binaries

Less than a decade ago about 4000 close binaries were known in the Galaxy with an additional 200 or so systems identified in the Magellanic Clouds and M31. Now, over 10 000 close binary stars (CBS), mostly eclipsing binaries, are known. The vast majority of these CBS were discovered during the last several years alone, and many more are expected to be detected within the next few years. Most of these stars were found as spin-offs of microlensing surveys. Interestingly, over half of the currently-known CBS are found outside our Galaxy, primarily in the Magellanic Clouds. Two major areas of research, albeit complementary, are being currently addressed with this formidable database:

- Accurate distance measurements to the Local Group galaxies are crucial to calibrating the Cosmic Distance Scale and to determining the age and evolution of the Universe. As the first rungs on the cosmic distance ladder, these galaxies serve as calibrators for distance indicators which reach far beyond the bounds of the Local Group. The Large Magellanic Cloud (LMC), in particular, has been exploited for this purpose because of its proximity to the Milky Way and the relative brightness of its young population. Eclipsing binaries have been proven to make excellent "standard candles" that can potentially resolve the controversy and yield an accurate distance to the LMC, and to other Local Group galaxies. Also, binaries with Cepheid components are exceedingly interesting as they can yield simultaneous determinations of the Cepheid P–L zero point and the distance to the galaxy in which they reside.

- Every type of star is represented as a member of a close binary. This includes main sequence (as well as pre-main sequence) stars, giants, and supergiants, with the entire possible range of spectral types and masses represented. Moreover, white dwarfs, neutron stars, and black holes have

been found as members of CBS. These binaries continue to play vital roles in many areas of modern astrophysics. Extragalactic binaries, and in particular systems belonging to the Local Group, can be used to probe the structure and evolution of stars in environments with chemical histories that differ significantly from those of the solar neighborhood. For example, studying massive, metal deficient stars in the LMC ($\sim$1/2 solar) and SMC ($\sim$1/5 solar) is like using a "time machine" for studying the low-metallicity massive old disk O- and B-type stars that once populated our Galaxy about 5–10 billion years ago.

In addition, extragalactic eclipsing binaries yield essential fundamental data on masses, radii, and luminosities of stars (the mass-luminosity law), as well as the much needed checks of the evolutionary models for these extreme metal abundances, which are widely used in stellar population synthesis calculations. These data are crucial to understanding all stars, as well as the clusters and galaxies in which they reside, and the basic physical laws that govern their behavior. Local Group binaries can also be used to address other astrophysically important issues, such as the structure and dynamics of these galaxies and the enrichment of the interstellar medium.

Thus, extragalactic CBS provide laboratories for studying the combined effects of chemical composition (i.e., stellar opacities, convective overshooting, and stellar winds) on the structure and evolution of stars. Semi-detached O/B systems will provide data for more in-depth studies of mass exchange and mass loss during binary evolution than is possible from Milky Way binaries alone. Thus, the study of CBS in the Local Group galaxies is critically important to stellar astrophysics, galaxy formation and structure, and will improve the cosmic distance scale.

These encouraging prospects and the significant amount of work that has already been carried out in the field out prompted us to organize a Joint Discussion in the IAU General Assembly in Sydney. In the remainder of this paper we briefly summarize the main points of the meeting and give some ideas about possible future research directions.

2. Summary of the meeting and future prospects

The Joint Discussion was divided in three sessions focusing on different aspects of extragalactic binary star research, namely: I) Introduction and survey results, II) Binaries as distance indicators, and III) Astrophysics with extragalactic binaries.

Session I started with a general introduction on some general aspects related to extragalactic CBS by E. F. Guinan (with the most necessary historical perspective), followed by overview presentations of the Local Group galaxies by M. L. Mateo and the long-lasting problem of the distance to the LMC by D. R. Alves. Special attention was given to the smaller galaxies in the Local Group, some with very interesting star formation histories, which certainly contain numerous CBS awaiting discovery and investigation. With regard to the LMC distance, the thorough comparison presented clearly indicates a decrease in the spread of recent results thus pointing towards a imminent resolution of the secular debate on the so-called "short" and "long" distance scales. Interestingly, the

average of the estimations seem to converge to a value close to the "canonical" value of 18.5 for the distance modulus.

The remainder of the first session focused on the results from the MACHO, OGLE and DIRECT surveys. Besides statistical studies, the representatives of the different groups, K. H. Cook for MACHO, A. Udalski for OGLE, and L. M. Macri for DIRECT, reviewed the methods and instrumentation used to obtain light curves that meet the requirements for the determination of accurate elements. Also, efforts to further observe and analyze some of the most promising candidates were discussed. If an exciting result presented at the Joint Discussion had to be singled out, this would be perhaps the announcement by the OGLE group of three candidate RR Lyr type variables in LMC eclipsing binaries. The analysis of these objects (if confirmed as such) will provide a unique opportunity to obtain absolute dimensions of RR Lyr variables for the first time, as well as an accurate determination of the period-luminosity zero point.

One of the fields within extragalactic CBS research that has driven most of the recent attention is the use of eclipsing binaries as distance indicators. Session II was entirely devoted to this exciting topic with several presentations discussing the methods, results and suitability of different eclipsing binary types. The first oral paper within this session by J. V. Clausen provided a thorough review of the methods used to estimate distances to detached systems and a detailed study of the errors sources. Also, the importance of multicolor photometry as well as ultraviolet observations for the determination of effective temperatures (one of the most critical pieces of information) were pointed out. It was recognized by several of the speakers in the Joint Discussion that the most demanding data set in CBS studies continues to be the acquisition of accurate radial velocity curves. The use of large telescopes (NTT, AAT, VLT) and space facilities (HST) has been necessary to provide reliable data. The results of an analysis of SMC eclipsing binaries were presented by R. W. Hilditch. This study represents a pioneering work based on a somewhat different approach of using a multi-object spectrograph (2dF at AAT) with relatively low resolution. The accuracy achieved in the derived distance, however, proves this as one of the most efficient observational programs. From the results presented at the Joint Discussion, double-lined eclipsing binaries nowadays provide a distance modulus to the LMC of 18.42 ± 0.05 mag and to the SMC of 18.90 ± 0.04 mag.

Distance determinations using semi-detached binaries and contact binaries were discussed by R. E. Wilson and S. M. Rucinski, respectively. Albeit still awaiting definite proof, these CBS may have some specific advantages over detached binaries. For example, semi-detached systems permit accurate determinations of the component's relative dimensions although their distorted shapes make temperature and radial velocity measurements a more difficult task. The case of contact binaries is different because it is possible to define an analogous relationship to the Cepheid's period-luminosity law. The accuracy reached in galactic systems is still somewhat modest but the prospects are definitely worth considering. Future eclipsing binary searches in the LMC should soon reach a limiting magnitude that will permit the discovery of numerous W UMa-type binaries and this distance determination method will reach full applicability.

Key systems among eclipsing binaries as distance indicators are those having a Cepheid variable as a component. Most notably, they permit simultaneous

determination of the distance to the LMC and the calibration of the Cepheid period-luminosity relationship. A few systems of this kind are known in the LMC, two of which were discussed by D. Welch. In spite of them not being fundamental mode pulsators the prospects from the work in progress are very good but complications in the light curve solution from intrinsic variability require a very careful job. Session II also included presentations by Y. W. Kang and A. Pigulski, who described their ongoing programs to observe and characterize eclipsing binaries in the LMC, mostly discovered from the EROS and OGLE surveys. The ultimate goal of both projects is to determine the absolute dimensions of the binary components and carry out distance estimations.

The final session of the Joint Discussion, Session III, focused on the application of extragalactic CBS to study aspects related to stellar astrophysics. In this respect, V. S. Niemela presented the efforts of her group to observe and analyze high-mass binaries in the LMC and SMC. The relative brightness of these O-type CBS has allowed their observation even with moderately-sized telescopes. Some of the stars in binaries with the known highest mass have been studied within this program and a calibration of the mass-luminosity relationship is in progress. In the second talk of the session, I. Ribas presented some results on the first steps towards using extragalactic eclipsing binaries as astrophysical laboratories. The aspects covered were the establishment of the mass-luminosity law, detailed comparison with stellar models (with consequences on the convective overshooting parameter), studies of stellar atmospheres, analysis of the the interstellar medium along the line of sight and use of eclipsing binaries to probe the structure of the host galaxies. Also, very good astrophysical insights can be gained from statistical studies such as those presented by P. North and C. Alcock based on the OGLE and MACHO databases. In the the first case, the statistical analysis of the sample permits the investigation of tidal evolution in the LMC and to assess the value of the critical radius for circularization in CBS. Similarly, C. Alcock discussed aspects related to the use of the MACHO database for statistical purposes and analyzed the distribution of orbital elements among eclipsing binaries.

Session III was completed with two presentations on supernovae by B. P. Schmidt and S. Van Dyk. The study of Type Ia supernovae (SNe) are certainly the most important contribution, albeit often neglected, of CBS research to cosmology. The intensive observation of SNe Ia has provided us with the surprising picture of an accelerating flat universe dominated by dark energy. B. P. Schmidt gave a comprehensive review of the role of SNe Ia in our current view of the Universe and also discussed efforts to better characterize the progenitors to these important binaries. This is a crucial aspect because currently we only have a phenomenological picture based on the shape of the light curve and a better physical understanding of what becomes a SN Ia would be most useful. Finally, S. Van Dyk presented a review of SNe and the role of binarity in each of the types. Apparently, binary systems are the likely progenitors of a very significant fraction of core-collapse SNe. To gather the necessary evidence, observational efforts have been directed towards a better characterization of SNe and their progenitors with encouraging results thus far.

With regard to future prospects, discussed in the closing talk by A. Giménez, it was emphasized that distance determination is not the only goal. The results

obtained thus far prove that a new field of stellar astrophysics can be now studied outside our own galaxy. Photometry is basically available but significant work is still required to obtain spectroscopy and to better characterize CBS. Also, even deeper photometry is needed to uncover fainter LMC/SMC binaries with A-type components and also binaries with pulsating components are definitely worth searching for. More and better ground-based observations are needed, requiring large telescopes for spectroscopy and interferometry (VLT, Keck, Magellan) and state-of-the-art instruments (e.g. multi-object via fiber-fed spectrographs). Ongoing and new surveys, including data mining of available catalogs (e.g. MACHO or OGLE) will provide additional candidates and data but more attention should be paid to well-calibrated surface brightness estimates (eventually using interferometry). Concerning space-based instruments, important results are expected from global astrometry as given by ESA mission GAIA (leading to a 20% accuracy for LMC individuals). On the other hand, interferometry from space, as expected to be available for example from SIM, will permit to resolve the photocenter motion of LMC and SMC long-period binaries and will open a new era of dynamical orbit determination through astrometry in extragalactic binaries.

In the remainder of these proceedings we include the title, author information and abstracts (often somewhat extended versions) of all oral contributions presented at the meeting. The full papers will be published by Elsevier in a special New Astronomy Reviews issue with I. Ribas and A. Giménez as guest editors. The authors wish to express their gratitude to the members of the Scientific Organizing Committee, J. V. Clausen, K. H. Cook, E. F. Guinan, R. W. Hilditch, V. S. Niemela, J. D. Pritchard, K. Z. Stanek, and A. Udalski, for their support and their contribution to make the Joint Discussion a success. Finally, we would like to thank, on behalf of the organizers of JD13, all speakers as well as the audience for a very enlightening and useful Joint Discussion (despite the allocation of number 13).